constructed from model carriers modulated by model C/A, and P (and, when applicable, A) codes.

Processing is said to be done in a code mode when the receiver "knows" the code in question. Because the C/A code is not encrypted, C/A modulation is usually processed in the code mode, using the published C/A code. Processing is said to be done in an encryption mode when the receiver does not "know" the code in question. More specifically, processing is said to be done in an encryption mode when the receiver does not "know" the A code with which the P code is modulated. Hence, the present invention is characterized as a method of encryption-mode processing.

The figure is a block diagram of signal processing according to the invention. The received GPS signal is down-converted from radio frequency (RF) to baseband to obtain two pairs of quadrature components — one pair for L1, the other for L2. Unlike in some prior methods, there is no cross-processing of signals between the L1 and L2 P channels. Instead, each of the two quadrature components obtained from each RF signal, independently of the other components, is counterrotated with its respective model phase, correlated with its respective model P code, and then successively summed and dumped over pre-sum intervals substantially coincident with chips of the respective encryption code. In the encryption mode, the effect of the unknown A-code sign flips is reduced, for each quadrature component of each RF signal, by combining selected pre-sums. The resulting combined pre-sums are then summed and dumped over longer intervals and further processed to extract the amplitude, phase, and delay for each RF signal. The precision of the resulting phase and delay values is approximately four times better than that obtained from conventional cross-correlation of the L1 and L2 P signals.

In comparison with prior encryption-mode receivers, a receiver according to this invention offers greater signal-to-noise ratios for the L1 and L2 P signals, and greater precision in the phases and delays of these signals. Unlike the prior receivers, this receiver offers the capability for separate and independent tracking of the L1 and L2 P signals to eliminate fading crossover, separate and independent measurement of the L1 and L2 P amplitudes, the option of dual-band measurements without a separate L1 P channel, removal of a half-cycle ambiguity in the L2 P phase, and the option of operation in either the code mode or the encryption mode with maximum commonality of hardware and software between modes. Finally, this processing method would still work even if the L1 and L2 P codes were to be encrypted with different A codes.

This work was done by Lawrence Young, Thomas Meehan, and Jess B. Thomas of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

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Refer to NPO-30367, volume and number of this NASA Tech Briefs *issue, and the page number.*

Integrated Formulation of Beacon-Based Exception Analysis for Multimissions

BEAM has become a broadly applicable, highly capable means of automated diagnosis.

NASA's Jet Propulsion Laboratory, Pasadena, California

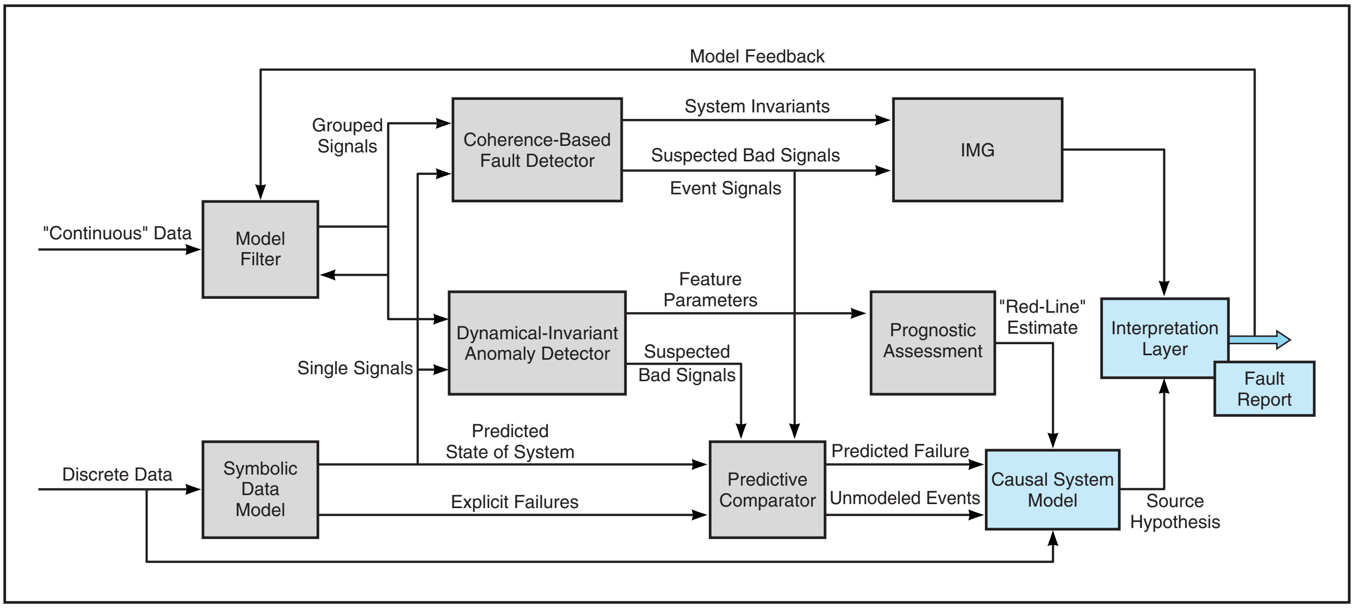
Further work on beacon-based exception analysis for multimissions (BEAM), a method of real-time, automated diagnosis of a complex electromechanical systems, has greatly expanded its capability and suitability of application. This expanded formulation, which fully integrates physical models and symbolic analysis, is described architecturally in the figure.

In a typical application, BEAM takes the form of an embedded software suite executing onboard the system under study, though many off-board data analysis engines have been constructed as well. The BEAM software performs real-time fusion and analysis of all system observables. BEAM is intended to reduce the burden of diagnostic data collection and analysis currently performed by both human operators and computers. In the case of a spacecraft or aircraft, BEAM enables onboard identification and characterization of most anomalous conditions, thereby making telemetry of larger quantities of sensor information to ground stations unnecessary. Previously BEAM has been described in several prior *NASA Tech Briefs* articles: "Reusable Software for Autonomous Diagnosis of Complex Systems" (NPO-20803) Vol. 26, No. 3 (March 2002), page 33; "Beacon-Based Exception Analysis for Multimissions" (NPO-20827), Vol. 26, No. 9 (September 2002), page 32; and "Wavelet-Based Real-Time Diagnosis of Complex Systems" (NPO-20830), Vol. 27, No. 1 (January 2003), page 67.

The new formulation of BEAM expands upon previous advanced techniques for analysis of signal data, utilizing mathematical modeling of the system physics, and expert-system reasoning. These components are integrated seamlessly, making possible analysis of varied information about the monitored system, including time-correlated signal performance, state information, software execution, operator command execution, and convergence to state and physical models. BEAM software is highly adaptable and can be implemented at relatively low cost in terms of processor power and training, and does not require special sensors. Unlike some prior methods of automated diagnosis, BEAM affords traceability of its conclusions, which allows system experts to completely reconstruct its decision path for greater operator confidence or to aid analysis of novel conditions. Principal among BEAM's strengths is its excellent performance in detection and classification of such novelty, meaning faults of previously unknown — and untrainable — type.

In the BEAM architecture, discrete sensor information, state information, and commands are fed as input to the symbolic model, and quantitative sensor data is input to a simplified physical model of the system. These modules are designed to leverage existing system models, which can be high or low fidelity. The symbolic model aids signal-based analysis in terms of mode selection or other discrete outputs. The physical model improves sensitivity through separation of predictable and unpredictable signal components.

Time-varying quantities are analyzed in two groups: (1) signals with a high degree of correlation to others, or signals that are not isolated in a diagnostic sense, are passed to the coherence-analysis component of BEAM; (2) signals that may uniquely indicate a fault, as well as those already suspected to be faulty, are passed through



This **BEAM Architecture** expands upon the original BEAM formulation in the following respects: (1) incorporation of physical models, (2) integration of symbolic reasoning components, (3) statistical and stochastic modeling of individual signals (augmenting or supplanting prior wavelet-based modeling), (4) trending to failure for individual signals and cross-signal features, and (5) enumeration of results using an expert system.

feature-extraction components. This split allows BEAM to consider very complex faults in the system, including interference faults or miscommunication that escape univariate detection methods, while retaining robustness in poorly redundant systems or in the face of gross nonlinerity.

The components of BEAM described in the figure are summarized as follows:

- The model filter combines sensor data with predictions from a real-time physical model. The inclusion of physical models, where available, is the most efficient way to incorporate domain knowledge into signal-based data analysis.
- The symbolic data model interprets status variables and commands to provide an accurate, evolving picture of the system mode and requested actions.
- The coherence-based fault detector tracks the cobehavior of temporally varying quantities to expose changes in internal operating physics.
- The dynamical invariant anomaly detector tracks parameters of individual signals to sense subtle deviations and predict near-term behavior.
- The Informed Maintenance Grid (IMG) studies evolution of cross-channel behavior over the medium- and long-term operation of the system. It tracks consistent subthreshold deviations and exposes deterioration and loss of performance.
- The prognostic assessment yields a forward projection of individual signals, based upon their extracted parameters. It also provides a useful short-term assessment of impending faults and loss of functionality.
- The causal system model is a rule-based connectivity model designed to improve isolation of fault sources and identification of actor signals.
- The interpretation layer collates observations from all separate components and submits a single fault report in a format useable by recovery software, planners or other AI software, and/or human operators.

This work was done by Ryan Mackey, Mark James, Han Park, and Michail Zak of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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Determining Direction of Arrival at a Y-Shaped Antenna Array

The direction is computed from differences among times of arrival of signals.

John F. Kennedy Space Center, Florida

An algorithm computes the direction of arrival (both azimuth and elevation angles) of a lightning-induced electromagnetic signal from differences among the times of arrival of the signal at four antennas in a Y-shaped array on the ground. In the original intended application of the algorithm, the baselines of the array are about 90 m long and the array is part of a lightning-detection-and-ranging (LDAR) system. The algorithm and its underlying equations can also be used to compute directions of arrival of impulsive phenomena other than lightning on arrays of sensors other than radio antennas: for example, of an acoustic pulse arriving at an array of microphones.

The underlying equations express the differences among the times of arrival as functions of the inner products of (1) the unit vector of the direction of arrival and (2) the unit vectors along the baselines of the array. To obtain a solution for the unit vector (and thus, equivalently, the azimuth and elevation angles) of the direction of arrival,